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(71) Applicant: TELEFONAKTIEBOLAGET LM ERICSSON (publ)
126 25 Stockholm (SE)

(72) Inventors:
- Thielecke, Jörn
91056 Erlangen (DE)
- Wachsmann, Udo
91126 Schwabach (DE)

(74) Representative: Schmalz, Günther
Ericsson Eurolab Deutschland GmbH,
Nordostpark 12
90411 Nürnberg (DE)

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(54) **Link adaptation for wireless MIMO transmission schemes**

(57) MIMO transmission methods are applied to communication systems in which a transmitter has more than one transmit antenna and a receiver has more than one receive antenna. Information to be transmitted is divided into a plurality of subsignals according to the number of used transmit antennas and each subsignal is processed separately before it is emitted by the respective transmit antenna. In the receiver the different receive signals are processed thus that subsignals are detected and decoded and the contribution of each detected and decoded subsignal is substracted from the receive signals and whereby a feedback channel from receiver to transmitter is used to send control information to the transmitter depending on the receive situation. In order to optimize the usage of the MIMO channel, the invention proposes the determination in the receiver of the link quality of each subsignal and the transmission of link quality information of each subsignal to the transmitter via the feedback channel so that in the transmitter properties of the subsignals can be controlled according to this link quality information.

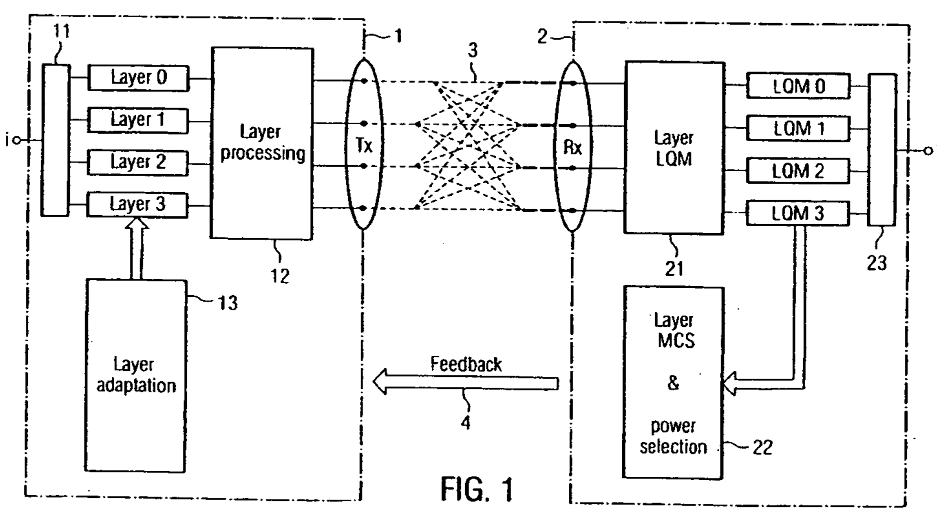

FIG. 1

EP 1 255 369 A1

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a wireless communication system for transmitting information between a transmitter having more than one transmit antenna and a receiver having more than one receive antenna, whereby information to be transmitted is divided into a plurality of subsignals according to the number of used transmit antennas. Each subsignal in such a system is processed separately before it is emitted by the respective transmit antenna. In the receiver adapted for such a system the different receive signals are processed thus that subsignals are detected and decoded. The contribution of each detected and decoded subsignal is subtracted from the receive signals. A feedback channel from receiver to transmitter is used to send control information to the transmitter depending on the receive situation

DESCRIPTION OF THE PRIOR ART

[0002] One method to efficiently utilise the available transmission potential of wireless communication channels is to use link adaptation (LA). Thereby, the transmitter has knowledge of one or more channel parameters reflecting the current ability of the channel for transmit data reliably. This kind of information is referred to as channel state information (CSI). Examples are signal-to-noise ratio or frame error rate.

[0003] There are already a couple of systems where link adaptation is included in the specification of the systems. The following subsections shall provide an overview of state-of-the art link adaptation schemes and its major features.

[0004] The classical form of link adaptation is to select a modulation and coding scheme for single-antenna links. However, if Multiple-input multiple-output (MIMO) transmission is considered, there are a lot more parameters of importance influencing the transmission properties than in the conventional case.

[0005] A channel having a single-antenna link between transmitter and receiver available is named as single-input single-output (SISO) channel. Link adaptation on SISO channels is the classical form of link adaptation as it is foreseen in most of the current systems. The core is that the transmitter has to select a modulation and coding scheme (MCS) out of a predefined set depending on the channel quality in order to meet the requirements of the considered service as good as possible. Examples for systems where such a link adaptation concept is foressen are: EDGE, HIPERLAN/2, and HSDPA.

[0006] Typically, the receiver measures the quality of the radio link. There are several possibilities to obtain such link quality measurements (LQM) like uncoded error rate or signal-to-noise-and-interference ratio. Based upon the LQM the receiver sends a recommendation to the transmitter which MCS seems to be appropriate in the next transmission period.

[0007] High-speed downlink packet access is the high-speed evolution of UMTS which is currently being standardised. Multiple-input multiple-output transmission is a transmission technique where multiple transmit and receive antennas are available. The proposal for MIMO transmission in HSDPA is related to V-BLAST. Thereby, the data stream is partitioned into independent layer data streams or code words. Every layer code word is transmitted from one transmit antenna.

[0008] The so-called V-BLAST transmission technique is known from EP 0 951 091 A2. In Such a known communication system comprises a transmitter with k transmit antennas. The transmitter is responsive to receipt a m-dimensional transmit symbol vector from a source. The transmit vector is transmitted over m of the k transmitt antennas using a predetermined modulation technique where $k \geq m \geq 1$. A receiver having n antennas for receiving signals from that receiver as n-dimensional received signal vectors, where $n \geq m$ comprises a detection processor that processes the n-dimensional received signal vector to form an estimate of the m-dimensional transmit symbol vector. Then the processor determines the best reordering of the transmitted components and then processes the received vector to determine the reordered transmitted symbol components. Such processing starts with the lowest level of the reordered components, and for each such level, cancels the interfering contributions from lower levels, if any, and nulls out interfering contributions from higher level, if any. This system also provides a feedback channel from receiver to transmitter for optimizing the selection of transmitt antennas.

[0009] Most MIMO transmission techniques work similar to V-BLAST in the sense that the data stream is partitioned into multiple independent portions which are processed, e.g. encoded, separately. The possibility to extract the transmitted information back at the receiver out of the layer signals strongly depends on the current propagation conditions on the MIMO channel. Therefore, the task of link adaptation for MIMO transmission is at least two-fold: a) determine the number of layers that can be separated again at the receiver and b) determine the appropriate MCS per layer.

[0010] In HSDPA, the following information is signalled back on the uplink serving as criteria for selection of the downlink transmission settings:

- Number of receive antennas
- Recommendation: which transmit antennas shall be used
- Recommendation: one MCS for all layers

[0011] The current MIMO proposal for HSDPA (TSG-RAN Document R2-010503) assumes at most four antennas at either the transmit or receive site. Ac-

cordingly, the following transmit modes are defined:

1. 4x4 MIMO (i.e. 4-layer MIMO with 4 transmit and 4 receive antennas)
2. 2x4 MIMO (i.e. 2-layer MIMO with 2 transmit and 4 receive antennas)
3. Space-time transmit diversity STTD (i.e. non-layered transmission with 2 transmit antennas to exploit transmit diversity)
4. Single antenna (non-layered conventional transmission from 1 antenna based on selection diversity)

on the correlations in the current MIMO channel matrix.

[0012] A MIMO transmission technique proposed by the applicant is multi-stratum space-time coding (MSSTC). Thereby, the data stream is partitioned into multiple independent portions, here called strata. In the patent application EP 00121621.7, there is already mentioned that the power and the rates of the strata can be adapted individually per stratum. However, it is not further specified where to base this adaptation upon.

[0013] Discrete matrix multitone (DMMT) and variants thereof is proposed in Gregory G. Raleigh; John M. Coffi, "Spatio-Temporal Coding for Wireless Communication", IEEE Transaction on communications, Vol 46, No. 3, March 1998, pages 357-366 and Ada S. Y. Poon; David N. C. Tse; Robert W. Brodersen, "An adaptive Multi-Antenna Transceiver for Slowly Flat Fading Channels", available at http://degas.eecs.berkelev.edu/~dtse/pub.html as a means to optimally exploit the transmission potential of a MIMO channel. The transmission is based on OFDM, whereby every OFDM subchannel is subject to MIMO propagation conditions. The core regarding link adaptation is that it is assumed that the transmitter has full knowledge of the channel, i.e. full or maximum channel state information of every OFDM subchannel is available at the transmitter. With this knowledge it is possible to predistort the transmitted signal such that a diagonal channel without interfering signal is generated. Additionally, with the waterfilling technique the transmitted power is distributed among the diagonal MIMO channels to achieve the maximum throughput.

[0014] While DMMT assumes full channel state information at the transmitter, the techniques to be discussed here, assume that only partial channel state information is available. The ideas for MIMO transmission presented in Syed Ali Jafar; Siram Vishwanath; Andrea Goldsmith, "Channel Capacity and Beamforming for Multiple Transmit and Receive Antennas with Covariance Feedback" availbale at http://wsl.stanford.edu/Publications.html, and Christopher Brunner; Joachim S. Hammerschmidt, Alexander Seeger; Josef A. Nossek, "Spacer-Time Eigenrake and Downlink Eigenbeamformer: Exploiting Long-term and Short-Term Channel Properties in WCDMA, available at http://www.nws.e-technik.tu-muenchen.de/cgi-bin/nws/publications, named covariance feedback and Eigenbeamforming, are based on the long- or mid-term correlation matrix of the channel. That means that the receiver estimates the channel matrices over a certain time period and calculates the correlations among the entries in the channel matrix. Instead of signalling the instantaneous channel matrices which means a rather high feedback signalling rate only updated versions of the correlation matrix are sent back to the transmitter. Since the correlation matrix mainly depends on the current scatterer scenario, which is usually assumed to change rather slowly over time compared to fast fading effects, the correlation changes also only rather slowly with time. Therefore, firstly, the rate to update the correlation matrix may be rather small, and, secondly, the estimation of the correlation matrix may be averaged over a rather long time period and thus a rather good estimate may be obtained.

[0015] Having the correlation (or covariance) matrix available at the transmitter, the eigenvectors of the correlation matrix are taken to steer the transmitted signals towards the eigenvalues of the correlation matrix. Additionally, waterfilling with respect to the eigenvalues is applied. This can e.g. imply that some eigenvalues are discarded for transmission since their amplitude is too small and it is therefore more valuable to put the power in the stronger eigenvalues.

PROBLEM OF EXISTING TECHNOLOGY

[0016] The crucial property of layered MIMO transmission compared to conventional SISO (sinlge-input single-output) transmission, is that in addition to the perturbation of the receive signal by noise and interference from other users, the layer signals are perturbed by other layer's signals. This kind of interference has often by far the greatest impact on the transmission potential on the considered layer.

[0017] Since MIMO transmission is a quite recent transmission technique, there are up to now very few detailed proposals how to assess the described kind of inter-layer interference and how to use it for link adaptation.

OBJECT OF THE INVENTION

[0018] Therefore it is an object of the invention to find link quality measurements that suit best for MIMO transmission.

[0019] The initial idea to introduce layered MIMO transmission was to facilitate the task at the receiver by extracting the transmitted information stage by stage in a serial decoding process rather in one big decoding step. Thereby, one layer is detected and decoded and afterwards its contribution is subtracted from the receive signal. This kind of detection and decoding is called serial interference cancellation.

[0020] The information that can be reliably transmitted by one layer depends firstly, on the current channel conditions, and secondly, on the decoding order in the

serial interference cancellation process. Therefore, it should be obvious that the transmission capabilities of the different layers and hence the appropriate layer MCS may be quite different for different layers. That means if the parameters assigned to all layers are identical the transmission potential of the MIMO channel might not be fully exploited in most of the cases. Therefore it is a further object of the invention to present a solution for best exploitation of a MIMO channel While for V-BLAST in HSDPA, switching off of antennas is considered as one ingredient in the link adaptation concept, for other transmission techniques like MSSTC, there are not yet such proposals available. In MSSTC, there is a full usage of all transmit antennas regardless of the number of strata being currently used. All schemes that are characterised by this property shall be named stratified MIMO schemes in the following in order to distinguish to layered MIMO schemes.

[0021] Depending on the channel conditions, it could be that the potential rate of one or more strata is very small. Then, it is usually advantageous to reduce the number of strata, i.e. the number of independent strata. Therefore it is another object of the invention to present a solution that adapts appropriately the transmitted signal in case of switching off strata while all transmit antennas are still in use.

SUMMARY OF THE INVENTION

[0022] To optimize the explotation of the MIMO channel the link quality of each subsignal is determined in the receiver, information of each subsignal is transmitted to the receiver via the feedback channel and that in the transmitter properties of the subsignals are controlled by the link quality information.

[0023] The question is what are the means to assess the transmission potential per layer (in general per partition) at the receiver. To elaborate further on this topic, the following notation shall be introduced. The transmission on layer m (partition m) shall be characterised by two parameters: code rate $R^{(m)}$ and power $P^{(m)}$. This applies to all possible layers m, $m=0,\ldots,M-1$, where M is the total number of layers. For example, M may be equal to the number of transmit antennas N_T.

[0024] One measure of the link quality per layer m is the (Shannon) capacity of this layer $C^{(m)}$. In order to calculate the layer capacity, the current channel matrix **H** as well as the current signal-to-noise ratio at the receiver input SNR are needed or, in other words, need to be measured. It should be noted here that the term noise is understood in a quite general sense. Every disturbance either from co-channel interference or from thermal noise or from anything else shall be comprised in the noise power. For the calculation of the capacity continuously distributed Gaussian symbols are assumed at the channel input. Although this does not reflect the discrete-valued transmission alphabets like QAM that are used in reality, results obtained by the Gaussian assumption reflect very well the real transmission conditions. How to calculate the layer capacities in detail is described in [8] for the MIMO transmission schemes V-BLAST, D-BLAST, and MSSTC. The method can be easily generalised to other MIMO techniques like multilayer space-time coding (MLSTC) [9] as well. The results of the capacities can be directly taken to give a recommendation for the MCS selection per layer, this will be proposed in more detail in Solution 4.2.

[0025] MIMO transmission offers a substantial performance gain when the channel is feeded appropriately. The way of link adaptation proposed here tries to exploit a big portion of this potential also in practice.

BRIEF DESCRIPTION OF THE INVENTION

[0026] An embodiment of the present invention is described below, by way of examle only, with reference to the accompanying deawings, in which:

Fig.1: shows a layered MIMO communication system with a feedback channel according to the invention.

EMBODIMENT OF THE INVENTION

[0027] Fig. 1 shows a MIMO communication system with a transmitter 1 and a receiver 2. In this embodiment the transmitter 1 provides four transmit antennas and the receiver 2 also provides four receive antennas. Payload information **i** is splitted in the transmitter by a demultiplexer 11 into four subsignals which are also called Layer 0, Layer 1 Layer 2 and Layer 3. The demultiplexer can be controlled in a way that the data rate of each subsignal may be choosen different from the data rates of the other subsignals. The subsignals are processed ba a layer processing unit 12 to achieve the desired MIMO properties. The subsingals are transmitted to the receiver2 wherby they are subjected to a MIMO channel. In the reciever 2 the different layers are decoded and the link quality of each received subsignal (each layer) is determined by a layer link quality means 21. In this embodiment the link quality information is evaluated in the receiver in a evaluation unit 22 and control information is generated that is send to the transmitter1 via a feedback channel 4. The skilled person in the arte will readily appriciate that the link quality information may be send as such to the transmitter 1 and could be evalutated as well in the transmitter 1. However, the control information, which for example optimizes individually for each subsignal to be transmitted e.g. the code rate, modulation scheme and/or the transmitt power thus allows to adapt each layer to the current MIMO channel.

More detailed information is given in the following:

First embodiments:

[0028]

- 4 layers shall be used
- Given a certain measured channel matrix and a certain SNR the capacities per layer for a certain MIMO scheme, e.g. MSSTC, are given by:
  - $C^{(0)} = 1.53$ [bit/symbol].
  - $C^{(1)} = 2.32$ [bit/symbol].
  - $C^{(2)} = 3.98$ [bit/symbol].
  - $C^{(3)} = 4.23$ [bit/symbol].
  - Due to the assumed serial interference cancellation at the receiver, at least, for MSSTC, it is always the case that the capacities are increasing from lower to higher layers given that the lower layers are decoded first.

[0029] It is crucial to mention that it has to be taken into account that the capacity assumes ideal channel coding that cannot be accomplished in practice. In order to incorporate real coding schemes a certain gap in terms of SNR to capacity has to be used.

Example:

[0030]

- Convolutional codes with 64 states and different rates shall be used as MCS
- The gap of real coding depends on a) the used coding scheme itself, and b) the target error rate.
- If a target BER of 10-5 is given, a gap of 4 dB can be assumed.
- That means if the measured channel SNR is at X dB, the capacity values have to be taken at X-4 dB in order to reflect the loss due to convolution coding.

Benefit of capacity calculation:

[0031]

- The capacity expressions derived in [8] have a very simple structure. They look like: C = log2(det(**I** + SNR*[**HGG**^{H}**H**^{H}]), where **H** is the channel matrix and the matrix **G** comprises the operations to generate the transmitted signal. (.)H denotes the Hermitian operator for matrices.
- Therefore, the measured channel matrix and SNR can be directly inserted in the expressions.
- However, for certain MIMO schemes like e.g. MSSTC, where multiple time instants have to be considered, the involved matrices become quite big, e.g. up to 32x32 for 4 transmit antennas. Hence, the computational load for direct calculation (of the matrix determinants) might be too high.
- There is a need to search further on for less computationally expensive ways of capacity calculations like some table lookup functionality based upon the channel matrix or maybe its singular values.
- A further benefit of the described capacity calculation is that it automatically works best for linear MMSE detection. For different detection scheme, the MMSE capacity values serve still as a useful estimate. There is no need to set up the MSSE matrices or in general the equations for the linear detection algorithm explicitly.
- Real coding can be easily incorporated as described above.

SINR per layer

[0032] Layers are transmitted according to the used MIMO scheme, e.g. MSSTC. At the receiver input, all layers are superimposed in general due to the propagation conditions of the MIMO channel. Usually, with linear interference suppression schemes prior to channel decoding the layer signals are separated to a certain extent. The task of detection in this context can be always described as finding a trade-off between suppressing the interference from other layers, enhancing the noise, and saving complexity in the detection scheme. Given the used detection scheme and again the measured current channel matrix as well as the measured SNR, it is possible to derive expressions for the useful signal power, the power of interference from other layers, and the noise power after detection at the input of the channel decoder. Putting these terms together give the signal-to-noise-and-interference ratio SINR, whereby interference here only means the interference from other MIMO layers rather than the interference from other users.

[0033] The calculated SINR values per layer may now be used in the way as the SNR values are typically used in link adaptation for SISO channels, for details see Solution 4.2.

Benefits:

[0034]

- By calculating the SINR per layer the parameter that is mainly characterising the transmission on the considered layer is obtained.
- SINR is a measure that is commonly used also for SISO channels although there interference typically means multiuser interference.

Singular values of the channel matrix

[0035] In order to get more insight into the properties of the channel matrix and into the inter-layer interference situation for MIMO transmission, a singular value decomposition of the channel matrix is very helpful:

$H=U^*S^*V^H$, where the columns of **U** are the left-hand singular vectors, the columns of **V** are the right-hand singular vectors and **S** is a diagonal matrix containing the singular values itself.

[0036] The singular values itself give already a very helpful indication on the inter-layer interference situation for transmission.

Examples:

[0037]

- MSSTC: the layer capacities are more or less uniquely determined by the singular values. Therefore, it is sufficient to know the singular values in order to appropriately assign rates to the individual layers.
- BLAST type of schemes: layer capacities are determined by **S** and **V**. That means in practice that the rough interference situation is given already by the singular values and, so-to say, the variance of it is then generated by the current singular vectors in **V**.

Benefits:

[0038]

- The normalised singular values (maximum singular value is set to one) of the channel matrix are changing much more slowly than the channel matrix itself.
- That implies that an update of the singular values is not necessary very fast with respect to one symbol interval
- This gives the possibility to obtain quite accurate estimates.
- It is one opportunity to get a mid- or even long-term statistic of the channel.

Channel correlation matrix

[0039] The previously described measures capacity and SINR relate more to the instantaneous channel matrix. This seems to be appropriate when it is possible to update the selected MCS quite frequently. On the other hand, if the layer parameters shall be kept fix over a longer time period, a long-term measure like the correlation matrix of the channel is more appropriate.

[0040] The receiver is estimating various channel matrices in a certain time period and calculates the correlation among the matrix elements. The resulting correlation matrix reflects the type of scatterer environment that is present in the interesting time period. Roughly speaking, the correlation matrix shows whether there are strong or weak correlations in the channel matrix. More mathematically spoken, the distribution of the eigenvalues of the correlation matrix give a more precise picture of the correlation situation.

Examples:

[0041]

- All eigenvalues of the correlation matrix are equal
- The meaning is that there is a rich scattering environment and e.g. it is valuable to create as many layers as transmit antennas.
- Only one eigenvalue of the correlation matrix is significantly greater than zero The meaning is that there is e.g. one dominating path the transmitted signal is emitted along. In such situations, it is possible to more or less fully exploit the transmission potential by creating only one layer.

Benefits:

[0042]

- The correlation matrix may be measured over a rather long time period. Therefore, noise in the estimate can be suppressed very effectivly and, hence, the obtained estimate can be made quite accurate.
- Less signalling rate for feedback is required since the correlation matrix or the derived MCS recommendations, respectively, are updated rather seldom.

WER, BER

[0043] For completeness, the typical measures WER and BER shall be mentioned here. For MIMO link adaptation, WER and BER are understood as WER and BER per layer.

Obtaining the BER

[0044]

- The (raw or uncoded) BER is obtained by comparing hard decided bits before decoding with the decoded versions (state-of-the-art in SISO transmission, nothing really new in for MIMO layers).

Obtaining the WER

[0045]

- In data transmission, there are usually CRC checks involved at some protocol stage in order to ensure the correctness of a transmitted data packet with a very high probability.
- These CRC checks may be used to obtain a statistic on the word or frame errors in the receiver without knowing the actually transmitted data.

Features:

[0046]

- The calculation or measurement of WER and BER is rather simple.
- However, most often the accuracy of the obtained values is insufficient, especially for the WER. The reason is that in order to obtain a high accuracy measurements over a long time period are necessary. Depending on the mobility of the involved environment the channel and hence the transmission conditions have already changed significantly during this long time period. Therefore, the obtained WER or BER does not reflect any longer the current channel conditions.

RATE AND POWER ASSIGNMENT STRATEGIES FOR LAYERED MIMO

[0047] In principle, it has to be distinguished between two basic cases:

a) the assignment shall be adapted according to long-term characteristics
b) the assignment shall be adapted to the instantaneous transmission conditions

[0048] In order to distinguish these two cases, strategies belonging to case a) are named slow adaptive and those belonging to case b) are named fast adaptive.

Slow-adaptive assignment based upon correlation matrix

[0049] The idea is that prior to transmission, so-to-say off-line, representative correlation matrices are chosen which reflect typical transmission conditions for the considered antenna configuration. For these representatives, many random channel matrices according to the considered correlation matrix are generated and the layer capacities $C^{(m)}$ for the MIMO transmission technique which is applied in the considered system, e.g. MSSTC, are calculated for every channel. Depending on the features of the system where MIMO transmission shall be applied, the random channel matrices taken for the described experiment prior to transmission may be either power-controlled or power-normalised to a target SNR value or they are calculated for a target average SNR. Since random channels are involved the capacity of every layer can be regarded as a random variable. One characteristic of such a random variable is its probability density function (PDF) or its cumulative distribution function (CDF).

[0050] For the typical cases in MIMO transmission the quasi-stationary condition holds. That means that the channel is quasi-constant during the transmission of one code word, but it has changed considerably between the transmission of two code words. Given this quasi-stationary condition the value of the layer capacity $C^{(m)}$, where the CDF value is equal to X % corresponds to a word error rate of X % and is therefore referred to as the X%-outage capacity $C^{(m)}_{X\%}$.

[0051] The X%-outage capacities per layer $C^{(m)}_{X\%}$ having calculated or to be more specific having measured by off-line simulations or experiments are the basis for a slow-adaptive link adaptation concept. Given the values $C^{(m)}_{X\%}$ for a target SNR may serve as an indication which are the best suited ratios for the layer rates $R^{(m)}$ that have to be assigned. This concept shall be further specified by the following example.

Example:

[0052]

- Antenna configuration: 4 transmit and 4 receive antennas
- The range of eigenvalue distributions of the correlation matrix spans from only one eigenvalue unequal zero to 16 identical eigenvalues
- As an example 4 representatives of the correlation matrix shall be chosen as follows:
  - A 16x16 random matrix **M** is generated
  - an eigenvalue decomposition of this random matrix is performed to obtain random eigenvectors: $\mathbf{M} = \mathbf{QLQ}^H$, where **Q** contains the eigenvectors of **M** as columns and **L** is a diagonal matrix containing the eigenvalues.
  - it has to be ensured that the eigen vectors have non-zero entries each, otherwise correlations between some elements might be discarded. In this case, a new 16x16 random matrix is chosen.
  - The 4 representatives are chosen by defining 4 different matrices **L** with 4 different eigenvalue distributions.
  - $\mathbf{L}_1$ = diag{1,1,1,1, 1,1,1,1, 1,1,1,1, 1,1,1,1}
  - $\mathbf{L}_2$ = 4/3*diag{1,1,1,1, 1,1,1,1, 1,1,1,1, 0,0,0,0}
  - $\mathbf{L}_3$ = 2*diag{1,1,1,1, 1,1,1,1, 0,0,0,0, 0,0,0,0}
  - $\mathbf{L}_4$ = 4*diag{1,1,1,1, 0,0,0,0, 0,0,0,0, 0,0,0,0}
  - Diag{.} means a diagonal matrix with the elements on the main diagonal given in brackets.
  - The 4 representative correlation matrices are then obtained by:
    - $\mathbf{M}_i = \mathbf{QL}_i\mathbf{Q}^H$, i=1,2,3,4.
    - A target SNR of 10 dB is chosen.
    - The applied MIMO scheme is MSSTC.
    - The target word error rate shall be 1 %. Thus, the 1%-outage capacities per MSSTC layer are the interesting measures.
    - For the representative correlation matrix $\mathbf{M}_1$, random channel matrices are generat-

ed and the 1%-outage capacities per layer $C^{(m)}_{1\%}$ are calculated.

- Assume the result for MSSTC may for simplicity look like:
  - $C^{(0)}_{1\%}$ = 2 [bit/symbol].
  - $C^{(1)}_{1\%}$ = 2.5 [bit/symbol].
  - $C^{(2)}_{1\%}$ = 2.8 [bit/symbol].
  - $C^{(3)}_{1\%}$ = 3 [bit/symbol].
  - Therefore, the rates per layer should be chosen in a similar ratio. To reflect e.g. typical code rates, one strategy could be to define the goal for the normalised layer code rates:
    - $[R^{(0)}\ R^{(1)}\ R^{(2)}\ R^{(3)}] / R^{(3)} = [2/3\ ¾\ 1\ 1]$
    - This procedure is then repeated for every all other representatives of the correlation matrix $\mathbf{M}_2$, $\mathbf{M}_3$, $\mathbf{M}_4$ as well.
    - During transmission, the channel correlation matrix is measured and classified as to belong in one of the 4 classes characterised by the representatives. This may be accomplished e.g. by at least approximately calculating the eigenvalues of the correlation matrix.
    - Given the classified "correlation class", the the normalised layer code rates are known as described above.
    - The actually chosen layer rate then depends a) on the instantaneously measured SNR on the channel and b) on the available set of MCS per layer. One possible strategy there is:
      - The rate of the last (interference-free) layer is chosen firstly according to the MCS appropriate to the current channel conditions (may be obtained by conventional SISO link adaptation since this layer is interference-free)
      - All other rates are selected based upon the given normalised rates. The actual layer rates may then be chosen according to the MCS with the closest rate (rounding) or according to the MCS with next-lower rate.

[0053] It shall be emphasised here that the X%-outage capacity is only one measure the rate assignment could be based upon. Other possible measures are e.g.:

- Average capacity per layer
- Estimated WER out of SINR calculations:
  - Similar to calculating layer capacities layer SINRs may be calculated as described above
  - These SINR values may be mapped to one WER per MCS in the available set. This mapping is typically be done by simulations for the AWGN channel over SNR. The layer SINR is then identified with the AWGN SNR and the corresponding WER is taken out of the simulation result curve.
  - Given a target WER per layer, there is usually one corresponding layer MCS fulfilling this target WER with the highest possible layer rate
  - The normalised layer rates may then be defined by ratios of the MCS rates and the procedure continues as described above.

Fast-adaptive assignment based upon layer capacities

The concept shall be illustrated by the following example:

Example:

[0054]

- Antenna configuration: 4 transmit and 4 receive antennas
- Available rates of convolutional coding are ½ and ¾. Used modulation schemes are QPSK, 16QAM and 64QAM. Thus, the predefined set of MCS per layer expressed in terms of rate per layer is, $R^{(m)}$ = {1, 1.5, 2, 3, 4.5} [bit/symbol].
- The applied MIMO scheme is MSSTC.
- The layer capacities for the current channel conditions are
- $C^{(0)}$ = 1.53 [bit/symbol].
- $C^{(1)}$ = 2.32 [bit/symbol].
- $C^{(2)}$ = 3.98 [bit/symbol].
- $C^{(3)}$ = 4.23 [bit/symbol].
- The problem is now that the channel being actually available for transmission will already differ by the measured one. That implies also that the calculated layer capacity will look differently. The degree of change in layer capacities depends a) on the time duration between channel measurement and actual transmission, b) on the mobility of the environment, and c) on the used MIMO scheme.
- The above-mentioned issues have to be considered in form of a margin when assigning the layer rates. The margin itself then also depends on the points a), b), and c) like before.

- As an example let us define a capacity margin such that the calculated capacities are reduced by 0.5.
- The goal now could be defined as to find the MCS the rate of which being the closest to the capacity minus margin (rounding). Alternatively, the MCS with the next lower rate could be selected.
- For the considered example, the rate assignment with rounding and the exemplary margin of 0.5 results in
- $R^{(0)} = 1.0$ [bit/symbol].
- $R^{(1)} = 2.0$ [bit/symbol].
- $R^{(2)} = 3.0$ [bit/symbol].
- $R^{(3)} = 3.0$ [bit/symbol].

[0055] The described example is one way for the rate assignment. The central point is certainly how the margin may be obtained and how it is used. The margin maybe used either as an additive value or as an relative value scaling down the capacities.

Ways to obtain the margin:

[0056]

- The important issue is how the channel matrix changes over time and what is the impact on the applied MIMO scheme
- In order to assess this, many pairs of two random channel matrices that are correlated in time according to a) the time period lying between channel measurement and actual transmission and b) the assumed mobility of the environment may be generated.
- For each pair of channel matrices the layer capacities are calculated and either the differences or the ratios between the individual layer capacities are treated as a new random variable.
- Based upon the the PDF or CDF of this random variable and depending on the target error rates the margin can be determined

Example:

Fast-adaptive assignment based upon layer SNR

[0057] The same strategies as described for capacity may be applied if SINR is taken as LQM per layer (this needs to be explained in further detail at a later stage).

Power assignments

[0058] All solutions described above exclusively treat the assignment of rates to the individual layers. One basic concept for the assignment of different powers to the individual layers could be to assign the powers such that the rate of every layer can be made equal. That means e.g. that the powers are varied until all layer capacities are equal or until all layer SINRs are equal referring to the above-introduced LQMs.

ADAPTING THE NUMBER OF LAYERS TO THE LONG-TERM CHANNEL SITUATION

[0059] The 'slow-adaptive assignment based upon the correlation matrix' in Solution 4.2 describes a way to assign rates or MCS per layer based on long-term measurements, namely the correlation matrix. In addition to adapt the layer rates, there is also the possibility to totally switch off or on layers and adapt by this the number of layers appropriately to the observed long-term channel situation. This will be further elaborated in the following.

[0060] Regarding the BLAST-type of schemes switching off layers implies switching off antennas and therefore a certain degree of the transmission capacity might be lost, because only parts of the channel are used. This kind of adaptation is already propsed in HSDPA as explained above.

The MIMO schemes that are under investigation in particular for this solution are layered schemes where the layer signals are superimposed in a way that all transmit antennas are used at one transmission interval regardless of the number of layers that is used. One representative in the class of these MIMO schemes is MSSTC. The key now is that the generation of the transmitted signal depends on the number of layers that shall be used. That means it is e.g. not sufficient to always generate firstly a transmit signal with maximum number of layers and set the power of some of the layers equal to zero afterwards.

[0061] The number of layers in use could be selected e.g. according to

- The number of eigenvalues in the correlation matrix being significantly greater than zero
- The number of singular values in the instantaneous channel matrix being significantly greater than zero
- Ensure a certain minimum rate per layer, that means if e.g. an MCS of rate1.0 was necessary to cope with the inter-layer interference and the current SNR and the minimum code rate has been set to 2.0, then this layer would be switched off.

Example MSSTC:

[0062]

- Antenna configuration: 4 transmit antennas, arbitrary number of receive antennas
- Number of necessary layers was set to 2 because some of the above-mentioned criteria
- Then, the MSSTC transmitted signal is generated by a space-time code for 4 antennas while the orthogonal transform, e.g. DFT or Hadamard, has length 2 reflecting the number of used layers.

Benefits:

[0063]

- The more layers are present the more interference between layers is generatred in general
- If the same data rate can be achieved with less number of layers the receiver becomes simpler and usually the performance improves since there are less losses due to imperfect receiver solutions.

[0064] MIMO transmission offers a substantial performance gain when the channel is feeded appropriately. The way of link adaptation proposed here tries to exploit a big portion of this potential also in practice.

TERMINOLOGY AND ABBREVIATIONS

[0065]

AWGN	Additive white gaussian noise
BER	Bit error rate
CDF	cumulative distribution function
CSI	Channel state information
DMMT	Discrete matrix multitone
HSDPA	High-speed downlink packet access (high-speed mode of UMTS)
LA	Link adaptation
LQM	Link quality measurement
MCS	Modulation and coding scheme
MIMO	Multiple-input multiple-output
MMSE	Minimum mean square error
MSSTC	Multi-stratum space-time coding
PDF	probability density function
SINR	Signal-to-noise-and-interference ratio
SISO	Single-input single-output
SNR	Signal-to-noise ratio
V-BLAST	Vertical BLAST (BellLabs layered space-time architecture)
WER	Word or frame error rate

Claims

1. A method of transmitting information in a communication between a transmitter having more than one transmit antenna and a receiver having more than one receive antenna, whereby information to be transmitted is divided into a plurality of subsignals according to the number of used transmit antennas and each subsignal is processed separately before it is emitted by the respective transmit antenna and whereby in the receiver the different receive signals are processed thus that subsignals are detected and decoded and the contribution of each detected and decoded subsignal is subtracted from the receive signals and whereby a feedback channel from receiver to transmitter is used to send control information to the transmitter depending on the receive situation,
characterized in that,
in the receiver the link quality of each subsignal is determined, information of each subsignal is transmitted to the receiver via the feedback channel and that in the transmitter properties of the subsignals are controlled by the link quality information.

2. A method according to claim 1 wherby in the receiver the determined link qualities are evaluated to generate control information that is send to the transmitter.

3. A method according to claim 1 wherby the determined link qualities are send to the receiver and are evalutated in the receiver to generate control information to control each transmitt subsignal.

4. A method according to claims 1, 2 or 3 whereby the control information is used to control the transmission mode, e.g. modulation schemes or code rates of the subsignals in the transmitter.

5. A method according to claims 1, 2, 3 or 4 wherby the control information is used to control the transmit power of each subsignal in the transmitter.

6. A transmitter for a MIMO transmission system having more than one transmit antenna whereby information to be transmitted is divided into a plurality of subsignals according to the number of used transmit antennas and each subsignal is processed separately before it is emitted by the respective transmit antenna and whereby on a feedback channel control information from a receiver is received,
characterized in that,
information of the link quality of each subsignal is received via the feedback channel and that the transmitter controls properties of the subsignals based on the link quality information.

7. A receiver fcr a MIMO communication system having more than one receive antenna, whereby receive signals of a respective receive antenna are processed thus that subsignals are detected and decoded and the contribution of each detected and decoded subsignal is subtracted from the receive signals and whereby a feedback channel from the receiver to a transmitter is used to send control information to the transmitterer depending on the receive situation,
characterized in that,
in the receiver the link quality of each subsignal is determined, information of each subsignal is transmitted to the receiver via the feedback channel for

adapting the properties of the subsignals in a respective transmitter.

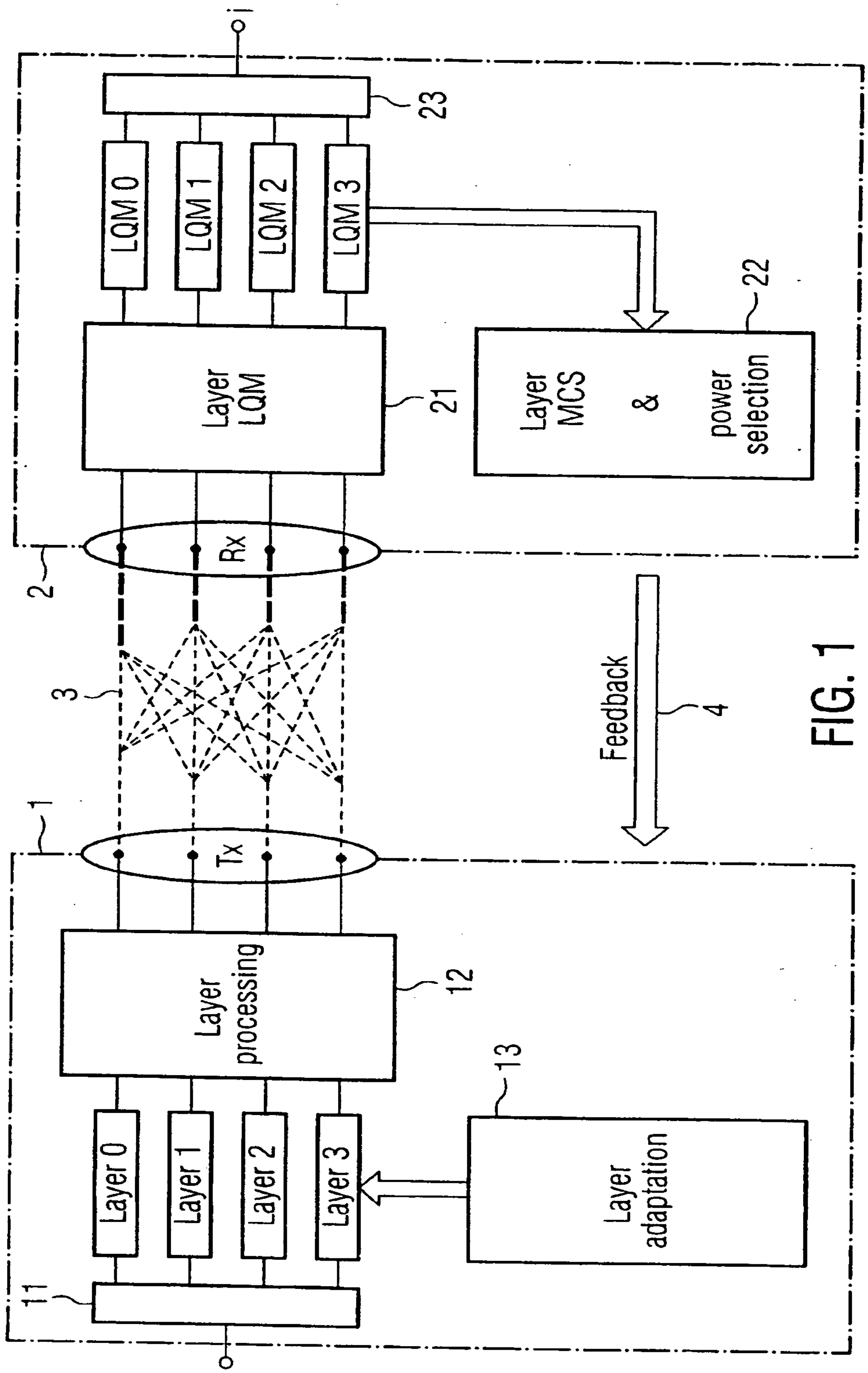
i
23
LQM 0
LQM 1
LQM 2
LQM 3
22
Layer LQM
21
Layer MCS
&
power selection
Rx
2
3
Feedback
4
1
Tx
Layer processing
12
13
Layer 0
Layer 1
Layer 2
Layer 3
Layer adaptation
11
i

FIG. 1

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EUROPEAN SEARCH REPORT

Application Number
EP 01 11 0838

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	2 October 2001	Marzenke, M

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EUROPEAN SEARCH REPORT

Application Number
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